Chapter 1

Introduction

1.1 MIMO OFDM Systems

In recent years, Internet usage has increased in leaps and bounds and has billions of users. Internet usages like VOD-Video On Demand, E-Mail, Browsing, Contacts etc...demand high speed Internet that leads to a need for broadband adoption. At the same time, cellular systems have made it possible for people to stay connected with the world from almost anywhere, resulting in a concept while OnTheMove. With the increase in users and their demands, the broadband market continues to grow, which in turn leads to development of new technologies like Wimax [1], LTE, LTE-advanced for broadband wireless. These technologies provide usage flexibility, high throughput and more coverage.

Wireless channel[42] is the main barrier for these new technologies. It causes impairments like noise addition, interference, multipath fading effects etc. in the transmitted signal. This demands very complex algorithms in the wireless receiver to overcome these impairments. Previous technologies like GSM[45] use FDM(Frequency Division Multiplexing), while CDMA uses orthogonal codes and spread spectrum to overcome channel impairments. These systems have their own limitations. For example, FDM requires guard band for separation to overcome interference between two consecutive users. Similarly, CDMA[45] needs to generate orthogonal sequences with zero correlation which is difficult to achieve if the number of users increases indefinitely. This leads to OFDM[31][66] (Orthogonal Frequency Division Multiplexing). The concept is equivalent to dividing the channel frequency response into smaller orthogonal subbands. Since each adjacent frequency is orthogonal to each other, it eliminates the need of guard band for separation. Simultaneously, OFDM divides high data rate signal into multiple small data rate signals. Moreover, it can be implemented by simple FFT/IFFT techniques, leading to ease in implementation.
OFDM systems generally use CP (cyclic prefix) between two consecutive OFDM symbols to prevent ISI (Inter Symbol Interference). However, use of CP reduces spectrum efficiency. In existing literature, various methods like front end TEQ (Time domain Equalization) and channel shortening methods are proposed to reduce CP size. However, such TEQ suffers from noise amplification problem and gives poor performance in highly correlated channel environments. An alternative method to mitigate channel effects is providing sufficient CP and 1 tap FEQ (Frequency domain Equalization). In this method, the channel is estimated using preamble/pilot symbols. The estimated channel is then used in FEQ to eliminate or partially mitigate channel effects.

Fading can also be overcome by using diversity techniques like space, time, frequency and transmit diversity. Multiple versions of data are transmitted by using any of these parameters. The receiver receives multiple versions of the same data under different fading conditions. At the receiver, different combining methods like MRC (Maximal Ratio Combining), SC (Selection Combining) etc. are used to overcome narrowband fading with the help of array and/or diversity gain. Especially space diversity can be used to achieve high throughput/diversity gain by using a multiple transceiver antenna system, which creates multiple data pipes in the wireless channel. This results in multiple of Shannon capacity under favorable conditions. Such systems are called MIMO systems.

The two systems mentioned above, merged to a single system and gave robust performance and high throughput under wireless fading environment resulting in MIMO-OFDM systems [4]. Generally, MIMO-OFDM systems use CP of sufficient length to avoid ISI. For reliable demodulation of the transmitted data, a receiver mitigates channel impairments like signal attenuation and phase distortion. Such a reception strategy encourages reception methods called coherent demodulation [41]. There are some other methods also available for data demodulation even without compensating the channel distortions by suitably adapting the transmission modulation. Such a reception scheme called non-coherent demodulation [41][56], is inferior compared to coherent demodulation in terms of the bit error rate (BER) achieved for a given amount of transmit power [57]. For this reason, coherent reception is preferred in most of the modern communication systems.

1.2 Coherent Detection Requirement 1: Channel Estimation

Coherent demodulation acquires channel knowledge at the receiver to compensate for the channel induced distortions. The process of acquiring the channel knowledge is called channel estimation which is an integral part of most of the communication receivers nowadays. Apart from the knowledge of channel statistics, the channel estimator also requires knowledge of the instanta-
neous channel values to track the channel fading and compensate it. Available literature generally
describes two types of channel estimation methods. One is based on pilot based estimation and
the other is blind estimation[58][68]. Blind channel estimation methods avoid the use of pilots and
have higher spectral efficiency. However they suffer from high computational complexity and low
convergence speed required to derive statistical information from received data. On the other hand,
pilot based estimation uses pilots in block/distributed manner, depending on channel slow/fast fading
conditions. The transmitter transmits multiplexed pilot symbols along with data symbols to
acquire channel knowledge at the receiver. Such a channel estimation scheme is called Pilot Sym-
bol Aided Modulation (PSAM). The estimator then uses sophisticated signal processing algorithms
like LSE and MMSE to acquire the channel knowledge using pilot symbols.

Several authors have proposed channel estimation in frequency domain[63][35][8] for OFDM
systems using MMSE and LSE methods. However MMSE methods require prior knowledge of
channel statistics. Such information is not generally known which leads to modified LMMSE based
method. Still this method requires higher computations. On the other hand, LSE based method re-
quires just a scalar division to estimate the channel in frequency domain, but it leads to high channel
estimation MSE error since the estimation error gets spread over the whole frequency band. This
leads to time domain channel estimation which is more robust as it tracks down the inherent fre-
quency correlation among the taps.

Literature also addresses[51][20][13][55][27] time domain channel tracking methods like
MMSE, LMS, RLS adaptive estimators for OFDM systems. These methods use training symbols
for estimator coefficient updating. The author[14] suggested different methods according to their
convergence time and estimation error. As mentioned earlier, MMSE requires prior knowledge,
while LMS method only use currently received value for filter coefficient updating, resulting in slow
convergence. Filter updating based on a block of received data is more accurate, fast converging
and also averages out the noise effect. Such methods are called RLS based channel tracking. Still
RLS based updating suffers from high computation due to matrix inversion and singularity under
highly correlated channel conditions. This leads to proposed QR-RLS based channel estimation for
MIMO OFDM systems, which use preamble symbols for initial channel estimation. Literature[27]
shows use of DDCE method where first order Markov model is used for symbol by symbol channel
tracking after initial estimate. The above method produces better results in low and moderate
channel fading environments.

Under fast fading channel conditions, performance improvement is achieved by using time
domain QR-RLS channel estimator in-conjunction with scattered pilots in frequency domain. Lit-
terature [21] shows cases of only pilot based estimation where either Block, COMB, scattered
pilots are transmitted. Generally under fast fading conditions for doubly selective channels, pi-
lots are scattered with period of coherence bandwidth and coherence time. Various interpolation techniques[7] like linear, spline, 2D wiener based methods are then used for channel estimation using scattered pilots. Since pilot based estimation is merely a frequency domain estimation, performance is improved by combining QR-RLS based coarse channel estimation with pilot based fine estimation.

1.3 Coherent Detection Requirement 2: MIMO Data Detection

Once the channel is estimated, the next step in coherent MIMO system is to detect the correct symbols. Use of multiple antennas for transmission leads to various gains like array gain, diversity gain, etc.[40]. While array gain and diversity gain provide system reliability and increase the coverage area or decrease the required transmit power, SM (Spatial Multiplexing) increases the achievable data rate and hence the system capacity. Unfortunately, the Spatial De-multiplexing at the receiver is a challenging task.

Maximum Likelihood (ML) decoding achieves good error performance. However, its computational complexity increases exponentially with regard to the number of transmit antennas or spatial streams. On the other hand, linear filtering approaches such as Zero Forcing (ZF) or Minimum Mean Squared Error (MMSE) detection require low complexities. But their error performance is poor due to noise enhancement in the filtering process. VBLAST (Vertical Bell labs), an OSIC (Ordered Successive Interference Cancellation) method is an optimal solution in terms of complexity and performance. A lot of research has been done in OSIC based detection method. Since the conventional OSIC detectors detect symbols successively, it suffers from error propagation if the correct symbol is not found at the first layer. However, QR-LRL based OSIC guarantees minimum error propagation among all the OSIC detectors and achieves hard ML performance. But it suffers from Empty Vector Set problem while achieving soft ML performance.

Several remedies are addressed in the literature [54][26][16]. These include (i) deriving threshold value from non-suffering EVS layer, (ii) deriving log likelihood function from the remaining candidate vectors for non-existing bits and (iii) use of multiple QR decomposition structure for trying every constellation point at each layer. However, they all fall short in terms of complexity or performance, which leads to two proposed solutions to mitigate EVS.

1.4 Thesis Organization

This thesis is organized as follows: Previous work and proposed time domain QR-RLS chan-
nel estimator are described in detail in chapter two. Since all simulation parameters use Wimax (802.16m) standard phy. layer, an overview of Wimax system block diagram and down link frame format is given in chapter three. The fourth chapter describes joint coarse-fine QR-LS channel estimator for fast fading channel environment. Soft output generation and EVS (Empty Vector Set) problem for SM-MIMO data detection is defined in the fifth chapter. The sixth chapter provides two different solutions to mitigate EVS problem and produce soft output. The thesis is concluded in chapter seven.